Consultative Committee for Space Data Systems

REPORT CONCERNING SPACE DATA SYSTEMS STANDARDS

RADIO FREQUENCY AND MODULATION SYSTEMS

SPACECRAFT-EARTH STATION COMPATIBILITY TEST PROCEDURES

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- o National Space Development Agency of Japan (NASDA)/Japan.

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- o Department of Communications, Communications Research Centre (DOC-CRC)/Canada
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FOREWORD

This document is a CCSDS Report which contains explanatory material to supplement and clarify information contained in *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft* (reference [1]). In particular, this Report contains the procedures to be used in implementing Recommendation 401 (3.5.1) B-1, Minimum Set of Spacecraft-Earth Station Tests Required to Ensure Compatibility.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this Report may occur. This Report is therefore subject to CCSDS document management and change control procedures which are defined in reference [2].

Questions relating to the contents or status of this Report should be addressed to the CCSDS Secretariat.

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REFERENCES

[1] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Recommendation for Space Data Systems Standards, CCSDS 401.0-B. Blue Book. Washington, D.C.: CCSDS, September 1989 or later issue.

[2] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-5. Yellow Book. Issue 5. Washington, D.C.: CCSDS, May 1992 or later issue.

[3] *STDN Spacecraft RF Compatibility Test Procedures and Data Sheets*. STDN No. 408.1 Greenbelt, MD: GSFC, October 1980.

[4] *TDA Standard Practice, DSN Flight Project Interface Compatibility Test Design Handbook*. 810.8, Rev. C. Pasadena, CA:JPL, October 1983.

[5] *RF-Test Procedure for 15 M S-Band Station Weilheim*. DFS-TP-PD-4571-001. Oberpfaffenhofen:DLR, July 1986.

1.0 INTRODUCTION

1.1 PURPOSE

Recommendation 3.5.1 of *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*, CCSDS 401.0-B (reference [1]), proposes a minimum set of S/C-earth station tests required to ensure compatibility for the cross support of one Agency's spacecraft by another Agency's earth stations. In order to have a common understanding and to offer a comparable basis for these tests, this Compatibility Test Procedures Report was written.

Because this is a Report rather than a Recommendation, it does not represent a commitment by the Agencies to perform the compatibility tests according to these procedures. Nevertheless it is expected that the Agencies will make every effort to follow these guidelines.

1.2 ORGANIZATION

Compatibility test procedures described in this Report are assigned to five test groups:

- S/C Radio Frequency Tests;
- Telemetry Tests;
- Telecommand Tests;
- Ranging Tests;
- Earth Station Antenna Tracking System Tests.

In conducting the tests according these procedures, it is assumed that the S/C or suitcase model Radio Frequency (RF) Subsystem (RFS) provides the following auxiliary signals:

- S/C transmitter on/off;
- S/C telemetry on/off;
- S/C transmitter coherent/noncoherent;
- S/C modulation index high/low (optional);
- status of telecommand counter;
- verification of telecommand modes;
- at least one telemetry format;
- external input to S/C modulator;
- lock status of S/C receiver;
- static phase error of S/C VCO;
- VCO temperature;
- S/C receiver ranging on/off;
- S/C receiver Automatic Gain Control (AGC).

In addition to the above requirements, the S/C should allow the following control functions:

- S/C transmitter on/off;
- S/C telemetry on/off;
- S/C transmitter coherent/noncoherent;
- S/C modulation index high/low (optional).

In making the following tests, strict attention should be given to local power supply and environmental conditions.

2.0 S/C RADIO FREQUENCY TESTS

2.1 S/C Transmitter Frequency and Stability

Purpose: The purpose of this test is to verify that the noncoherent downlink frequency does not exceed specified limits.

Rationale: Excessive transmitter drift can necessitate readjustment of the earth station's receiving equipment.

Criteria: The total allowable frequency drift plus initial frequency offset over an 8-hour period shall be specified by the network authorities (e.g., *it shall not exceed ±0.005 percent of the assigned center frequency over an 8-hour period*).

Procedure:

1. Set S/C in noncoherent mode.[1]
2. Measure downlink RF frequency at RF level from cold start.
3. Measure downlink RF frequency stability at RF level over a period of 2 hours.
4. Monitor the ambient temperature of the S/C transmitter.
5. Plot the S/C carrier frequency against time and temperature.
6. Review the data to determine if the spacecraft frequency has drifted more than 1/4 of the specified allowable frequency deviation percentage from the assigned carrier frequency.
7. If this is the case, continue the test for 6 more hours.

[1] No spacecraft-mode changes or power-source changes should be made during the tests.

2.2 S/C Transmitter Residual Carrier Phase Stability

Purpose: The purpose of this test is to measure the spacecraft transmitter's residual carrier phase jitter, in degrees RMS, which is not tracked out by the earth station receiver's tracking loop.

Rationale: Excessive downlink carrier phase jitter will degrade both the tracking and telemetry systems' performance.

Criteria: The maximum allowable spacecraft transmitter phase jitter shall be supplied by the network authorities or by Agency standards (e.g., *unmodulated carrier phase noise shall be less than 2 degrees RMS in noncoherent and 5 degrees RMS in coherent mode*).

Description: To measure the S/C transmitter's phase jitter, generally a specific test configuration and specific equipment are required. This test equipment operates on the following principles:

The S/C transmitter's signal is connected to two identical receivers. Dynamic phase error outputs from the two receivers are sampled and converted to digital signals. A computer, with appropriate software, performs a cross correlation of the two dynamic phase error signals from the receivers.

The RMS voltage from each receiver contains that receiver's phase jitter plus the downlink carrier's phase jitter. When a cross correlation is performed on the signals from the two receivers which are locked to the same spacecraft carrier, the result is proportional to the downlink carrier's phase jitter alone. The RMS phase jitter of the downlink carrier on each receiver is computed from these voltages with the assumption that the phase variations generated by the receivers are independent of and uncorrelated with each other while the S/C phase jitter component from each receiver is correlated.

The phase jitter measuring equipment is calibrated with the tracking loop out of lock, giving a calibration factor relating voltage to degrees RMS. The residual phase jitter of each receiver is proportional to the ratio of the closed-loop response to the maximum-loop response when the loop is out of lock.

If a direct measurement of the phase noise is not possible, because of lack of adequate measurement equipment, a spectrum analyzer with a resolution BandWidth (BW) of equal to or less than 10 Hz can be used. It is then assumed that any modulation found is phase modulation. The procedure for using a spectrum analyzer follows:

Procedure:

1. Connect spectrum analyzer to RF output of the S/C.
2. Set downlink signal level near maximum allowable input level of spectrum analyzer.
3. Configure S/C to noncoherent mode with modulation off.
4. Set reference level of spectrum analyzer to unmodulated downlink carrier.

2.2 S/C Transmitter Residual Carrier Phase Stability (continued)

5. Display downlink frequency spectrum with the following spectrum analyzer settings:

resolution BW	=	10 Hz (maximum);
video BW	=	1 Hz (maximum);
frequency span	=	500 Hz (minimum).

6. Plot spectrum mask from spectrum analyzer.

7. Determine the ratio P_n/P_c of the highest sideband line to form an approximate ratio for the total one-sided noise power to carrier power, where:

   P_n = one-sided noise power of highest sideband line;

   P_c = carrier power.

8. Assuming a small noise modulation index, calculate and record the peak phase noise modulation index θ by means of the relationship:

$$P_n/P_c = J_1^2(\theta)$$

9. Determine and record the RMS equivalent noise modulation index *m* by means of the relationship:

$$m = \frac{\theta}{\sqrt{2}}$$

10. Set uplink signal level to the worst-case value with respect to the S/C (uplink worst-case level).

11. Set uplink RF carrier frequency to the S/C receiver's best lock frequency (identical to S/C receiver frequency determined in test 2.4).

12. Switch uplink on.

13. Lock S/C to unmodulated uplink carrier.

14. Configure S/C to coherent mode with modulation off.

15. Repeat STEPS 4 through 9.

2.3 S/C Transmitter RF Spectrum

Purpose: The purpose of these tests is to verify that neither residual sidebands nor spurious spectral components exceed specified levels.

Rationale: Excessive spurious signals can cause improper receiver lock and degradation of the telemetry, Doppler, and ranging data.

This test ensures that the spacecraft's transmitted spectrum is consistent with the bandpass characteristics of the earth station's receiver and that the level of spurious emissions, due to S/C nonlinearities, is within acceptable limits.

Criteria: Amplitude limits for residual sidebands and spurious signals shall be provided by the Flight Project or by Agency standards (e.g., *spurious emissions shall be at least 60 dB below the unmodulated carrier, measured with a reference bandwidth of 100 Hz*).

Procedure:

1. Connect spectrum analyzer to the RF output of the S/C.
2. Configure S/C to noncoherent mode with modulation off.
3. Set downlink signal level near maximum allowable input level of spectrum analyzer.
4. Set reference level of spectrum analyzer to unmodulated downlink carrier.
5. Display spectra with the following spectrum analyzer settings:

   resolution BW = 1000 Hz (maximum);

   frequency span = 10 MHz (or 100 MHz).
6. Switch telemetry modulation on.
7. Repeat STEP 5 using a smaller resolution BW.
8. Repeat STEPS 5 and 6 for all noncoherent downlink modes.
9. Set uplink RF signal level to minimum value expected at S/C during mission.
10. Set uplink RF frequency to best lock frequency.
11. Lock S/C's receiver to unmodulated uplink carrier.
12. Configure S/C to coherent mode with modulation off.
13. Repeat STEPS 4 through 7 for all coherent downlink modes.
14. Connect spectrum analyzer to the RF output of the S/C.
15. Repeat STEPS 2 through 13.
16. Plot all spectrum masks from spectrum analyzer.

2.4 S/C Receiver Best Lock Frequency Determination

Purpose: The purpose of this test is to measure the spacecraft receiver's best lock frequency.

Rationale: A S/C receiver's best lock frequency must be known by earth station operators in order to predict required uplink acquisition frequency sweep rate and range.

Criteria: The uplink carrier frequency offset from the nominal frequency[2] shall be furnished by the Flight Project or by Agency standards. For example:

> *The S/C receiver's best lock frequency shall not vary by more than ±35kHz from the nominal value including initial setting inaccuracies and variations due to voltage and temperature. An additional ±15kHz due to aging is permitted over a 7-year period.*

Procedure:

1. Set unmodulated uplink RF carrier signal level to minimum expected at S/C during the mission.
2. Configure S/C to noncoherent mode and monitor S/C receiver's lock status.
3. Record S/C receiver's VCO temperature after a 2-hour warm up period.
4. Lock S/C receiver at nominal uplink frequency.
5. Switch uplink off for a period of 20 minutes.
6. Switch RF uplink on at nominal frequency and verify acquisition.
7. If no acquisition occurs, adjust uplink frequency until S/C receiver locks.
8. Decrease RF uplink frequency until the S/C receiver loses lock.
9. Wait 5 minutes before continuing, to allow S/C receiver to stabilize.
10. Increase uplink RF frequency again until the S/C receiver locks.
11. Record the S/C receiver's VCO frequency at point of lock.
12. Sweep uplink RF frequency to nominal frequency as recorded in STEP 6.
13. Increase uplink RF frequency until the S/C receiver loses lock.
14. Wait 5 minutes before continuing, to allow S/C receiver to stabilize.
15. Decrease uplink RF frequency until the S/C receiver locks.
16. Record the S/C receiver's VCO frequency at point of lock.
17. Record the S/C receiver's VCO temperature.
18. Calculate the S/C receiver's best lock frequency by averaging frequencies recorded in STEPS 11 and 16.
19. Sweep uplink RF frequency to nominal frequency recorded in STEP 6.
20. Switch off RF uplink.

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[2] Nominal frequency is provided by the manufacturer of the flight radio system to the flight project.

2.4 S/C Receiver Best Lock Frequency Determination (continued)

21. Set unmodulated uplink RF carrier frequency to the S/C receiver's best lock frequency found in STEP 18.
22. Wait 10 minutes before continuing.
23. Switch on uplink RF carrier.
24. Verify that S/C receiver acquires the uplink RF carrier.

In cases where the telemetry frame rate is low or the earth station's sweep process can not be interrupted, the following alternate procedure is recommended.

Procedure:

1. Record S/C receiver's VCO temperature after 2 hours warm up.
2. Connect frequency synthesizer to RF input of S/C.
3. Set unmodulated uplink RF carrier signal level to minimum value expected at the S/C during the mission.
4. Lock S/C receiver at nominal[3] uplink frequency.
5. Measure the S/C receiver's VCO Static Phase Error (SPE) versus synthesizer frequency in a range of ±100kHz of the nominal uplink frequency.
6. Verify S/C receiver lock during calibration.
7. Connect S/C to an earth station uplink.
8. Set unmodulated uplink RF carrier signal level to minimum value expected at S/C during mission.
9. Lock S/C receiver at nominal[1] uplink RF frequency. Record value.
10. Switch uplink RF carrier off for a period of 20 minutes.
11. Record SPE vs. time.
12. Record S/C receiver's VCO temperature and verify that is the same as found in STEP 1 ±TBS degrees.
13. Calculate and record mean value of SPE.
14. Determine S/C receiver best lock frequency from calibration curve measured in STEP 5.
15. Sweep uplink RF carrier frequency to nominal[1] value recorded in STEP 9.
16. Switch off uplink RF carrier.
17. Set uplink RF frequency to the S/C receiver's best lock frequency reported in STEP14.
18. Wait 10 minutes before continuing.
19. Switch on uplink RF carrier.
20. Verify S/C receiver acquires uplink RF carrier.

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[3]Nominal frequency is provided by the manufacturer of the flight radio system to the flight project.

2.5 S/C Receiver Acquisition Frequency Range and Rate

Purpose: The purpose of this test is to verify the capability of the spacecraft's receiver to acquire RF carrier phase lock at a specified minimum signal level when the uplink carrier is initially statically offset from the receiver's Best Lock Frequency (BLF) and the uplink carrier is swept through the receiver BLF at a specified rate.

Rationale: This test ensures that the spacecraft's receiver and the earth station's transmitter can be operated over the required mission parameter range.

Criteria: The specific minimum and maximum acquisition-frequency ranges and rates shall be provided by the Flight Project or by Agency standards.

Procedure:

1. Set unmodulated uplink RF carrier signal level to minimum value expected at S/C during the mission.
2. Configure S/C to noncoherent mode and monitor S/C receiver's lock status.
3. Lock earth station's receiver to S/C's downlink RF carrier.
4. Lock S/C's receiver to earth station's uplink RF carrier which has been set to the S/C receiver's best lock frequency and record that frequency.
5. Switch uplink RF carrier off.
6. Sweep the earth station transmitter's frequency in a **NEGATIVE** direction to TBS kHz offset.
7. Switch uplink RF carrier on.
8. Sweep the earth station transmitter's frequency in a **POSITIVE** direction over a range greater than the frequency offset in STEP 6, using a standard station acquisition procedure, at a rate of TBS Hz/sec.
9. Verify that S/C's receiver locks during the sweep and record lock frequency.
10. Should acquisition fail to occur, reduce sweep rate and verify that sweep range includes S/C receiver's best lock frequency. Repeat STEP 8.
11. Sweep earth station transmitter's frequency to S/C's best lock frequency as recorded in STEP 4.
12. Switch uplink RF carrier off.
13. Sweep the earth station transmitter's frequency in a **POSITIVE** direction to TBS kHz offset.
14. Switch uplink RF carrier on.
15. Sweep the earth station transmitter's frequency in a **NEGATIVE** direction over a range greater than the frequency offset in STEP 13, using a standard station acquisition procedure, at a rate of TBS Hz/sec.

NOTE – TBS: to be selected by the earth station test conductor from the available earth station capabilities or from Agency standards.

2.5 S/C Receiver Acquisition Frequency Range and Rate (continued)

16. Verify that S/C's receiver locks during the sweep and record lock frequency.
17. Should acquisition fail to occur, reduce sweep rate and verify that sweep range includes S/C receiver's best lock frequency. Repeat STEP 15.
18. Sweep earth station transmitter's frequency to best lock frequency as recorded in STEP 4.
19. Repeat STEPS 4 through 18 with other frequency offsets and increasing sweep rates until acquisition fails to occur. Record results of successful acquisitions.
20. Set unmodulated uplink RF carrier signal level to maximum value expected at the S/C during the mission.
21. Lock S/C's receiver at best lock frequency.
22. Switch uplink RF carrier off.
23. Sweep the earth station transmitter's frequency in a **NEGATIVE** direction to TBS kHz offset.
24. Switch uplink RF carrier on.
25. Sweep the earth station transmitter's frequency in a **POSITIVE** direction over a range greater than the frequency offset in STEP 23, using standard station acquisition procedure, at a rate of TBS Hz/sec.
26. Verify that S/C's receiver locks during the sweep and record lock frequency.
27. If acquisition fails to occur, verify that S/C's receiver is at best lock frequency determined in Procedure 2.4. If not at best lock frequency, acquire RF carrier phase lock and sweep earth station transmitter's frequency until S/C receiver's VCO is at best lock frequency.
28. Increase the sweep rate to TBS Hz/sec and repeat STEPS 21 through 26 until S/C's receiver fails to acquire uplink RF carrier. Record value of immediately previous sweep rate (maximum rate where acquisition occurs).
29. Repeat STEPS 11 through 17 at sweep rates found in STEP 28.

NOTE – TBS: to be selected by the earth station test conductor from the available earth station capabilities or from Agency standards.

2.6 S/C Receiver Tracking Range and Rate

Purpose: The purpose of this test is to verify that the spacecraft receiver has the capability to track an uplink carrier frequency with a specified offset and at a specified rate.

Rationale: This test ensures that the spacecraft's receiver and the earth station's transmitter can be operated over the required mission parameter range.

Criteria: The specific minimum and maximum tracking-frequency rates and ranges shall be provided by the Flight Project or by Agency standards.

Procedure:

1. Set the unmodulated uplink RF carrier signal level to the minimum value expected at the S/C during the mission.
2. Configure S/C to noncoherent mode and monitor S/C receiver's lock status.
3. Lock earth station's receiver to S/C RF downlink carrier.
4. Lock S/C's receiver to earth station's unmodulated uplink RF carrier which has been set to the S/C receiver's best lock frequency and record that frequency.
5. Turn on telecommand and/or ranging modulation.
6. Sweep earth station transmitter's frequency, using standard station acquisition procedures, at a rate of ±TBS Hz/sec and range of ±TBS kHz.
7. Verify that the S/C's receiver remains in lock during the frequency sweep and record result.
8. Should the S/C's receiver drop uplink RF carrier lock, continue sweeping to best lock frequency. Reduce sweep rate or range and repeat STEPS 3 through 8.
9. Sweep earth station's transmitter frequency to S/C receiver's best lock frequency.
10. Verify that S/C receiver is at its best lock frequency.
11. Repeat STEPS 6 through 10 with other frequency sweep rates and ranges until maximum tracking rate and range are determined.

NOTE – TBS: to be selected by the earth station test conductor from the available earth station capabilities or from Agency standards.

2.7 S/C Receiver RF Acquisition Threshold

Purpose: The purpose of this test is to determine the S/C receiver's RF carrier acquisition threshold.

Rationale: This test ensures that the S/C receiver RF carrier phase-locked loop is compatible with the earth station's transmitter signal at specified threshold power levels. Phase instability and distortion, due either to the earth station's transmitter or the S/C's VCO, can raise the acquisition threshold of the S/C's receiver.

Criteria: The specified S/C receiver RF carrier acquisition threshold signal level shall be provided by the Flight Project or by Agency standards.

Procedure:

1. Set the unmodulated uplink RF carrier signal level to minimum value expected at the S/C during the mission.
2. Configure S/C to noncoherent mode and monitor S/C receiver's lock status.
3. Lock earth station's receiver to S/C downlink RF carrier.
4. Lock S/C's receiver to earth station's uplink RF carrier, which has been set to the S/C receiver's best lock frequency, and record that frequency.
5. Switch uplink RF carrier off.
6. Set unmodulated uplink RF carrier signal level to 5 dB below specified S/C receiver carrier threshold.
7. Switch uplink RF carrier on.
8. Increase uplink RF carrier signal level, at a rate of 1 dB per minute (or less), until S/C receiver RF carrier lock is detected. Record signal level.
9. Repeat STEPS 5 through 8 three times. Record signal levels.
10. Compute S/C receiver RF carrier threshold by averaging measurement results.
11. Set uplink RF carrier signal level 3 dB below S/C receiver carrier threshold computed in STEP 10.
12. Sweep earth station transmitter's frequency, using standard acquisition procedure, with acquisition parameters found in Procedure 2.5.
13. Increase uplink RF carrier signal level in steps of 0.5 dB until S/C receiver RF carrier lock is detected. Record signal level.
14. Verify that S/C receiver remains in lock.
15. Repeat STEPS 11 through 14 three times. Record signal levels.
16. Compute S/C receiver RF carrier acquisition threshold by averaging measurement results.

3.0 TELEMETRY TESTS

3.1 Telemetry Modulation Index

Purpose: The purpose of this test is to accurately measure the S/C's telemetry modulation index for both coherent and noncoherent modes.

Rationale: Modulation indices must be accurately determined so that power will be properly allocated to the several channels. These values are required for an optimum design.

Criteria: The Flight Project shall supply modulation indices for all bit rates plus allowable tolerances. For example:

data rate = *1200 b/s coded*;

mod. index = *1.1 RAD ±5%*.

Procedure:

1. Connect a spectrum analyzer to an appropriate Intermediate Frequency (IF) output in the earth station's receiver system.
2. Set unmodulated uplink RF carrier signal level to minimum value expected at S/C during the mission.
3. Configure S/C to noncoherent mode.
4. Set reference level of spectrum analyzer to unmodulated downlink carrier.
5. Switch telemetry modulation on.
6. Determine carrier suppression. Record value.
7. Calculate RF carrier telemetry modulation index for noncoherent mode and record. Turn off RF carrier and telemetry modulation.
8. For coherent mode modulation index measurements, set unmodulated uplink RF carrier frequency to S/C receiver's best lock frequency.
9. Switch uplink RF carrier on.
10. Lock S/C's receiver to uplink RF carrier at best lock frequency.
11. Configure S/C to coherent mode.
12. Repeat STEPS 4 through 7 for coherent mode.

NOTE – For low modulation indices, this procedure may produce inaccurate results. Verify resolution of spectrum analyzer.

3.2 Telemetry Receiver Carrier Threshold

Purpose: The purpose of this test is to determine the threshold sensitivity of the earth station's telemetry receiver to a signal from the S/C for both coherent and noncoherent S/C modes.

Rationale: This test ensures that the RF carrier loop of the earth station's receiver is compatible with the S/C telemetry signal at specified threshold power levels. Phase instability and distortion, due to either the S/C transmitter or telemetry receiver VCO, can raise the carrier threshold of the telemetry receiver.

Criteria: The specified telemetry receiver carrier threshold shall be provided by the network authorities. For example:

acquisition threshold	*TBS dBm*	*at*	*300 Hz (2 B_{LO});*
loss of lock	*TBS dBm*	*at*	*300 Hz (2 B_{LO}).*

Procedure:

1. Inject noise into earth station's receiver, either by appropriately positioning the antenna and using the receiver's ambient noise, or by using a calibrated noise source which is set to produce an equivalent Signal-to-Noise Ratio (SNR) in the earth station's receiver.
2. Configure S/C to noncoherent mode with telemetry modulation on and uplink RF carrier off.
3. Set downlink RF carrier signal level 5 dB above specified loss-of-carrier-lock threshold.
4. Lock the earth station's telemetry receiver to the S/C downlink RF carrier.
5. Decrease the downlink RF signal level until the telemetry receiver's carrier phase-locked loop drops lock.
6. Increase the downlink RF signal level until the telemetry receiver's carrier phase-locked loop reacquires the downlink.
7. Record the downlink RF carrier signal levels for both drop lock and reacquisition.
8. Repeat STEPS 3 through 7 three times.
9. Set uplink RF signal level to minimum value expected at the S/C during the mission.
10. Set uplink RF frequency to the S/C receiver's best lock frequency.
11. Switch uplink RF carrier on.
12. Lock S/C's receiver to uplink RF carrier which is set to best lock frequency.
13. Configure S/C to coherent mode with telemetry modulation turned on.
14. Repeat STEPS 3 through 8 for each operational downlink mode.

3.3 Telemetry Bit Error Rate

Purpose: The purpose of this test is to determine the total telemetry system's performance using the S/C's telemetry signal.

Rationale: Bit Error Rate (BER) is the ultimate performance measure of a digital telemetry system. It must be carefully determined in order to predict the telemetry system's performance throughout the mission.

Criteria: The Flight Project, or Agency standards, shall supply the required E_b/N_o and BER for all bit rates; for example:

Bit Rate	***Required E_b/N_0***	***Bit-Error Rate***
1200 b/s, coded	*3 dB*	*5×10^{-3}*
1200 b/s, uncoded	*7 dB*	*1.7×10^{-3}*

Procedure:

1. Inject noise into earth station's receiver, either by positioning the antenna and using the receiver's ambient noise, or by using a calibrated noise source which has been set to produce an equivalent SNR in the earth station's receiver.
2. Connect a spectrum analyzer to an appropriate IF output in the earth station's receiver system.
3. Measure the noise spectral density in the IF bandwidth using a spectrum analyzer.
4. If injecting noise using the earth station's receiver and positioning the antenna, record weather condition.
5. Configure S/C to noncoherent mode with telemetry modulation on.
6. Calculate carrier power required to achieve specified E_b/N_o.
7. Adjust RF carrier power level from S/C to calculated value.
8. Perform BER measurement over a sufficient period of time to acquire useful statistics. Record value.
9. Repeat this test three times, record values, and average results.
10. Repeat STEPS 6 through 9 at two other E_b/N_o values.
11. Repeat STEPS 6 through 10 for all other downlink coherent and noncoherent operational modes.
12. Calculate the total telemetry system loss.

NOTE – In the coherent mode, the uplink signal level should be set to minimum value expected at the S/C during the mission. The uplink frequency should be set to best lock frequency.

3.4 Telemetry Spectrum

Purpose: The purpose of this test is to determine the energy distribution of the telemetry modulation spectrum.

Rationale: The telemetry signal's spectral distribution provides information about cross modulation products and the occupied bandwidth. This data will be used to optimize receiving equipment parameters at earth stations.

Criteria: The specifications for the radio frequency spectral masks should be provided by the network authorities or by Agency standards. For example: *ESA Radio Frequency and Modulation Standard*, ESA PSS-04-105, Issue 1, December 1989.

Procedure:

1. Connect a spectrum analyzer to the S/C's RF output.
2. Set downlink RF signal level near the maximum allowable input level of the spectrum analyzer.
3. Configure S/C to noncoherent mode with all modulation on the downlink off.
4. Set reference level of spectrum analyzer to unmodulated downlink carrier.
5. Configure spectrum analyzer using the following settings:

   resolution BW = 100 Hz or smaller;

   the frequency band shall extend to at least -60 dBc points.
6. Switch telemetry modulation on. Record spectrum.
7. Repeat STEP 5 using a smaller resolution BW.
8. Repeat STEPS 6 and 7 for each noncoherent downlink operational mode with telemetry modulation on.
9. Set unmodulated uplink RF signal level to minimum value expected at the S/C during the mission.
10. Set uplink RF carrier frequency to the S/C receiver's best lock frequency.
11. Switch uplink RF carrier on.
12. Lock S/C's receiver to unmodulated uplink RF carrier.
13. Configure S/C to coherent mode with telemetry modulation off.
14. Repeat STEPS 4 through 7 for each coherent downlink operational mode with telemetry modulation on.
15. Plot all spectra from spectrum analyzer.

4.0 TELECOMMAND TESTS

4.1 S/C Receiver Telecommand and Carrier Thresholds

Purpose: The purpose of this test is to verify that the threshold values for the S/C receiver's telecommand subcarrier and RF carrier loops are correct and also to verify proper command performance at a specified minimum signal level.

Rationale: This test ensures that the S/C's RF carrier and telecommand subcarrier loops are compatible with the earth station's transmitted uplink signal at the specified threshold power levels. Phase instabilities and distortion, due either to the earth station's transmitter or the S/C's VCO, can raise the command system's threshold.

Criteria: Specific values for the S/C receiver's RF carrier and command subcarrier thresholds shall be provided by the Flight Project or by Agency standards. For example:

S/C receiver carrier threshold at P_c = *-151 dBm* $\pm$ *3 dB*;

command subcarrier threshold at P_c = *-142 dBm* $\pm$ *1 dB*.

Procedure:

1. Set unmodulated uplink RF signal level to 5 dB above the S/C's specified RF carrier threshold.
2. Configure S/C to noncoherent mode, turn telemetry modulation on.
3. Configure downlink receiver to properly monitor telecommand execution.
4. Lock the S/C's receiver to the uplink RF carrier at its best lock frequency.
5. Turn telecommand modulation on with a properly chosen telecommand modulation index and sequence. Repeat telecommand sequence continuously.
6. Reduce uplink RF signal level by 2 dB per minute in steps of 1 dB (or less) until telecommanding capability is lost.
7. Record minimum value of uplink RF signal level prior to telecommand loss.
8. Reset RF signal level to the value set in STEP 1 and repeat STEPS 6 and 7 three times.
9. Calculate the S/C receiver's telecommand threshold by averaging the several measurements and computing the telecommand data power at threshold.
10. Switch telecommand modulation off.
11. Verify that S/C receiver's RF carrier loop is in lock.
12. Reduce the uplink RF signal level by 1 dB (or less) per minute until the S/C receiver's RF carrier loop drops lock.
13. Record minimum value of uplink RF signal level prior to loss of carrier lock.
14. Repeat STEPS 12 and 13 three times.
15. Calculate the S/C receiver's RF carrier loop threshold by averaging the several measurements and computing the RF carrier power at threshold.

4.2 S/C Receiver Sensitivity to Telecommand Phase Modulation Index Variation

Purpose: The purpose of this test is to determine the earth station's minimum and maximum phase-modulation indices required to command the S/C.

Rationale: Knowledge of the permissible telecommand modulation index range is required to verify link performance.

Criteria: Specific minimum and maximum telecommand modulation indices shall be provided by the Flight Project or Agency standards.

Procedure:

1. Connect a spectrum analyzer to properly monitor the uplink RF signal's spectrum.
2. Set uplink RF signal level 5 dB above the theoretical telecommand threshold.
3. Configure S/C to noncoherent mode with telemetry modulation on.
4. Configure the downlink receiver to properly monitor telecommand execution.
5. Lock the S/C's receiver to uplink RF carrier at its best lock frequency.
6. Select a telecommand sequence which can be easily verified.
7. Set uplink RF carrier modulation index to specified minimum value.
8. Transmit a predetermined number (i.e., three) of commands and observe the S/C command counter.
9. Decrease uplink RF carrier modulation index in small increments and repeat telecommand sequence until the S/C fails to detect further commands.
10. Using the spectrum analyzer, record the difference between RF carrier and the first modulation sidelobe levels, in dB. Calculate the corresponding telecommand modulation index. Record value.
11. Set the uplink RF carrier modulation index to its specified maximum value.
12. Repeat STEPS 8 through 10 continuously using the telecommand selected in STEP6.
13. Increase uplink RF carrier modulation index in small increments until the S/C fails to detect further commands.
14. Using the spectrum analyzer, record P_C/P_{TOTAL}, in dB. Calculate the corresponding telecommand modulation index. Record value.

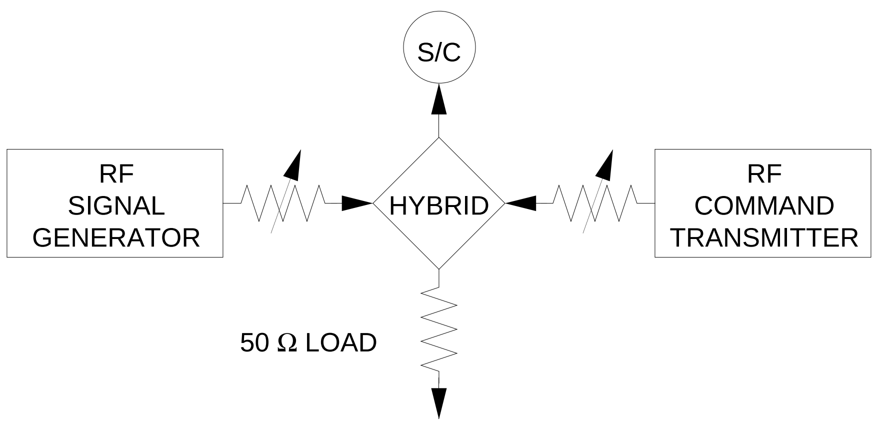
4.3 Telecommand Receiver Spurious Carrier Immunity

Purpose: The purpose of this test is to determine the S/C telecommand receiver's response to spurious RF carriers in the vicinity of this S/C's telecommand RF carrier frequency.

Rationale: When multiple RF carriers are present, interfering carrier or subcarrier cross products may be generated which have not been accounted for by analysis. These cross products may lie at frequencies which will cause degradation to either the tracking or the telecommand functions.

Criteria: Acceptance criteria and thresholds shall be provided by the Flight Project or by Agency standards.

Procedure: 1. Set the following test configuration:



2. Configure S/C to noncoherent mode with telemetry modulation on.
3. Configure downlink receiver to properly monitor telecommand execution.
4. Set uplink RF signal generator and telecommand transmitter to the S/C receiver's best lock frequency.
5. Set RF carrier telecommand modulation index to the specified value.
6. Set earth station's uplink RF power (P_{TOTAL}) so that telecommand data power level is 10 dB above the spacecraft's telecommand threshold.
7. Set the RF signal generator for a CW carrier to the same signal level as P_{TOTAL} in STEP 5.
8. Select a telecommand which can be easily verified and transmit continuously.
9. Record the difference in RF signal levels, in dB, between the interfering RF signal level and the RF telecommand transmitter signal.
10. Repeat STEPS 7 through 10 three times to verify the results and average.

4.3 Telecommand Receiver Spurious Carrier Immunity (continued)

11. Reduce the level of the interfering signal until the telecommand is executed.

12. Repeat STEPS 7 through 11 at frequencies offset by the telecommand Bit Rate (BR), the telecommand subcarrier, and the command subcarrier ±BR, and at other frequencies in steps of ±10 kHz within the bandpass.

4.4 Telecommand Receiver Spurious Modulation Immunity

Purpose: The purpose of this test is to determine the S/C telecommand receiver's response to spurious modulated carriers in the vicinity of this S/C's telecommand RF carrier frequency.

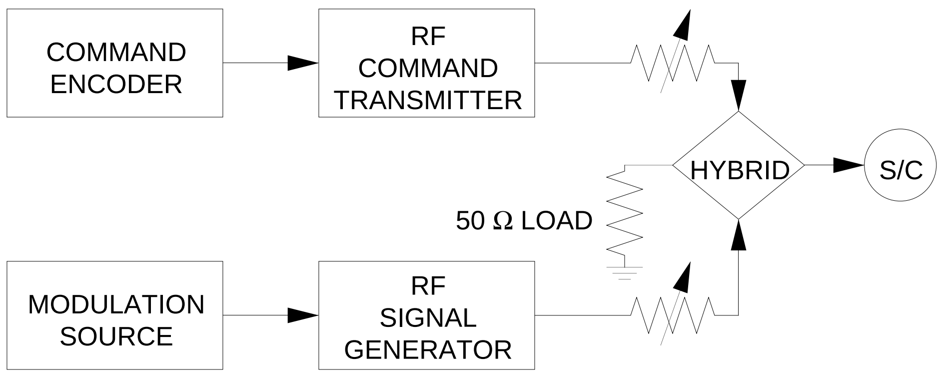
Rationale: Since the frequency bands allocated for telecommanding can also be used by other services, interference to telecommanding operations from other users is possible.

Since the allotted S/C command frequency bands are not exclusively used for S/C command operations, there is a good possibility of interference from an undesired source during command operations.

Criteria: Acceptance criteria and thresholds shall be provided by the Flight Project or by Agency standards.

Procedure:

1. Set the following test configuration:



2. Configure S/C to noncoherent mode with telemetry modulation on.
3. Configure downlink receiver to properly monitor telecommand execution.
4. Set uplink RF signal generator and telecommand transmitter to the S/C receiver's best lock frequency.
5. Set telecommand modulation index to specified value.
6. Set earth station's uplink RF power (P_{TOTAL}) so that telecommand data power level is 10 dB above the spacecraft's telecommand threshold. Set RF signal generator's power to a level 10 dB above the earth station's uplink RF power (P_{TOTAL}).
7. Modulate the signal generator with a frequency of 500 Hz (square wave) using a peak modulation index of 1.2 radians.
8. Continuously transmit a telecommand while reducing the level of the interfering signal until the telecommand is executed.
9. Record the difference in RF signal levels, in dB, between the interfering RF signal level and the RF telecommand transmitter signal.

4.4 Telecommand Receiver Spurious Modulation Immunity (continued)

10. Repeat STEPS 6 through 9 three times to verify the results and average.

11. Repeat STEPS 6 through 10 at frequencies offset by the telecommand bit rate (BR), the telecommand subcarrier, and the telecommand subcarrier ±BR, and at other frequencies in steps of ±10 kHz in the bandpass.

5.0 RANGING TESTS

5.1 Transponder Ranging Delay

Purpose: The purpose of this test is to accurately determine the S/C transponder's ranging delay for all relevant S/C RF modes.

Rationale: S/C transponder ranging delay is included in all range measurements and must be subtracted to give the true range.

Criteria: The Flight Project shall supply the predicted S/C delay vs. signal level desired. For example:

Total Uplink Power, dBm	*Ranging Delay, ns*
-95	*1500 ±3*

Procedure:

1. Set unmodulated uplink RF signal level to minimum value expected at the S/C during the mission.
2. Set uplink RF carrier frequency to S/C receiver's best lock frequency.
3. Configure S/C in coherent mode.
4. Set uplink RF carrier's ranging modulation index to specified value.
5. Lock the S/C's receiver to the uplink RF carrier at its best lock frequency.
6. Switch uplink ranging modulation on.
7. Lock earth station's receiver to S/C's downlink carrier and ranging signals.
8. Perform at least 10 ranging delay measurements; record and average results.
9. Repeat STEP 8 at other specified uplink RF signal levels.
10. Replace the S/C transponder with a zero-delay device (broadband mixer).
11. Set the same level as in STEP 1.
12. Perform at least 10 ranging measurements; record and average the results.
13. Repeat STEP 12 at the same RF uplink signal levels as used in STEP 9.
14. Calculate and plot the transponder's ranging delay for all applicable uplink levels (mean value measured in STEP 8 minus mean value measured in STEP 12).

NOTE – Verify that major and minor tones, if applicable, are equalized.

5.2 Ranging Downlink Modulation Index vs. Uplink Modulation Index

Purpose: The purpose of this test is to measure the nominal downlink range tone modulation index as a function of the uplink range tone modulation index at strong uplink signal levels.

Rationale: When the uplink is at a strong signal level, the telecommand data or ranging code will have a high SNR in the ranging channel. In this case, the nominal downlink range tone modulation index should be nearly independent of the received uplink ranging signal power.

Criteria: Nominal downlink RF carrier ranging modulation indices and limits shall be provided by the Flight Project or by Agency standards.

Procedure:

1. Connect a spectrum analyzer to properly monitor the downlink RF carrier and ranging signal levels.
2. Set uplink RF carrier to a strong signal level. Record value.
3. Set uplink RF carrier frequency to the S/C receiver's best lock frequency.
4. Configure S/C in coherent mode.
5. Set uplink RF carrier ranging modulation index to 1.5 radians.
6. Lock S/C to uplink RF carrier at best lock frequency.
7. Turn uplink ranging modulation on and telecommand modulation off.
8. Using the spectrum analyzer, measure the difference in power levels between the downlink RF carrier and the ranging tone. Record value.
9. Calculate the downlink ranging modulation index and record value.
10. Decrease the uplink RF carrier's ranging modulation index in steps of 0.25 radians from 1.5 radian to 0.25 radian. Repeat STEPS 8 and 9 for each setting. Record values.
11. Plot downlink RF carrier ranging modulation index as a function of uplink RF carrier modulation index.

5.3 Ranging Downlink Modulation Index vs. Uplink Signal-to-Noise Power

Purpose: The purpose of this test is to measure the effective downlink ranging tone modulation index as a function of the uplink signal-to-noise power.

Rationale: Because of the baseband Automatic Gain Control (AGC) amplifier in the S/C's ranging channel, the downlink range tone modulation index is a function of the received ranging signal-to-noise power. To verify proper link performance, this relationship is required.

Criteria: Nominal downlink RF carrier ranging modulation indices, limits, and transponder ranging channel bandwidth shall be specified by the Flight Project or by Agency standards. For example:

Nominal Downlink Ranging Modulation Index, radians	***Transponder Ranging Channel Bandwidth, kHz***
0.7 ± 5%	*300*

Procedure:

1. Connect a spectrum analyzer to properly monitor the S/C's downlink RF carrier and ranging signal levels.
2. Set uplink RF carrier to a strong signal level. Record value.
3. Set uplink RF carrier frequency to the S/C receiver's best lock frequency.
4. Configure S/C in coherent mode.
5. Set uplink RF carrier ranging modulation index to nominal value.
6. Lock S/C receiver to uplink RF carrier at best lock frequency.
7. Turn uplink ranging modulation on and telecommand modulation off.
8. Using the spectrum analyzer, measure the difference in power levels between the downlink RF carrier and the ranging tone. Record value.
9. Calculate the downlink ranging modulation index and record value.
10. Decrease the uplink RF signal level (P_{TOTAL}) until the received ranging tone level drops 1 dB relative to the downlink RF carrier.
11. Record uplink RF signal level (P_{TOTAL}).
12. Using the spectrum analyzer, measure the RF carrier-to-ranging tone power ratio and compute the downlink ranging modulation index. Record value.
13. Repeat STEPS 10, 11, and 12 until the received ranging tone level is 18 dB below the carrier.
14. Plot downlink ranging modulation index vs. uplink RF signal power (P_{TOTAL}).

5.4 Ranging Downlink Spectrum

Purpose: The purpose of this test is to measure the energy distribution of the ranging signal's spectrum.

Rationale: The spectral distribution is needed to compute cross modulation products and to determine the occupied bandwidth of the ranging signal. This information will be used to optimize the earth station receiving equipment's parameter settings.

Criteria: Specifications for the radio frequency spectral masks shall be provided by the network authorities or by Agency standards. For example: *ESA Radio Frequency and Modulation Standard*, ESA PSS-04-105, Issue 1, December 1989.

Procedure:

1. Connect a spectrum analyzer to properly monitor the S/C's downlink RF signal.
2. Set uplink RF signal level (P_{TOTAL}) to minimum value expected at the S/C during the mission.
3. Set downlink RF signal level near the maximum allowable input level to the spectrum analyzer.
4. Set uplink RF carrier frequency to the S/C receiver's best lock frequency.
5. Configure S/C to coherent mode with all modulation off.
6. Set reference level of spectrum analyzer to unmodulated downlink carrier.
7. Configure spectrum analyzer using the following settings:

   resolution BW = 100 Hz (maximum);

   the frequency band shall extend to at least -60 dBc points.
8. Set uplink RF carrier ranging modulation index to specified value.
9. Turn uplink ranging modulation on and telecommand modulation off.
10. Repeat STEP 7 using a smaller resolution BW.
11. Repeat STEPS 9 and 10 for each uplink and downlink mode with ranging modulation on. Record all spectra.
12. Plot all spectra from spectrum analyzer data.

6.0 EARTH STATION ANTENNA POINTING/TRACKING SYSTEM TESTS

6.1 Antenna Pointing/Tracking Receiver Carrier Signal Level Threshold

Purpose: The purpose of this test is to determine the threshold sensitivity of the earth station's antenna pointing/tracking system to a signal input from the spacecraft.

Rationale: This test ensures that the RF-carrier loop of the earth station's antenna pointing/tracking system is compatible with the S/C's downlink signal at specified threshold power levels. Phase instabilities and distortion, due either to the S/C's transmitter or earth station pointing/tracking receiver's VCO, can raise the carrier threshold of the pointing/tracking receiver.

Criteria: Specifications for the pointing/tracking receiver's carrier threshold shall be provided by the network authority. For example:

acquisition threshold	*TBS dBm at 300 Hz (2 B_{LO})*;
loss of lock	*TBS dBm at 300 Hz (2 B_{LO})*.

Procedure:

1. Set unmodulated downlink RF carrier level to 5 dB above the threshold specified for loss of RF carrier lock in the antenna pointing/tracking receiver.
2. Lock the earth station's antenna pointing/tracking receiver to the S/C's downlink RF carrier.
3. Decrease the downlink RF carrier level until the antenna pointing/tracking receiver drops lock. Record carrier level just prior to loss of lock.
4. Increase the downlink RF carrier level until the antenna pointing/tracking receiver reacquires lock. Record the carrier level when lock occurs.
5. Repeat STEPS 3 and 4 three times and average measurements for each downlink mode.

GLOSSARY

AGC automatic gain control

BER bit error rate

BLF best lock frequency

BR bit rate

B_{LO} single-sided threshold loop bandwidth

BW bandwidth

E_b/N_o energy per bit divided by noise spectral density

Hz hertz

IF intermediate frequency

RAD radian

RF radio frequency

RFS radio frequency subsystem

RMS root mean square

S/C spacecraft

SNR signal-to-noise ratio

SPE static phase error

TBS to be specified

TC telecommand

TLM telemetry

VCO voltage-controlled oscillator